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PERFORMANCE EVALUATION OF ATTACHED INFLATABLE DECELERATORS WITH MECHANICALLY DEPLOYED INLETS AT MACH NUMBERS FROM 2.6 TO 4.4

D. C. Baker

ARO, Inc.

November 1970

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ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

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AEDC-TR-70-254

PERFORMANCE EVALUATION OF ATTACHED INFLATABLE DECELERATORS WITH MECHANICALLY DEPLOYED INLETS AT MACH NUMBERS FROM 2.6 TO 4.4

D. C. Baker
ARO, Inc.

FOREWORD

The work reported herein was done at the request of the National Aeronautics and Space Administration (NASA), Langley Research Center, Hampton, Virginia, under Program Element 921E.

The test results presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-71-C-0002. The test was conducted in the Propulsion Wind Tunnel (16S), on August 28 and 29, 1970, under ARO Project No. PS1001. The manuscript was submitted for publication on September 25, 1970.

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This technical report has been reviewed and is approved.

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ABSTRACT

A test was conducted in the 16-ft Propulsion Wind Tunnel (16S) to determine the effect of reducing the inlet capture area on the deployment and performance characteristics of attached inflatable decelerators. Because of malfunctions of the inlet deployment mechanism, limited deployment data were obtained on only one of the decelerator models. Decreasing the inlet capture area increased the inflation time to 2.2 sec but resulted in poor decelerator inflation and low drag coefficient compared with previous AID models tested.

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NOMENCLATURE

C_{D_D} Drag coefficient with AID deployed $F_D/q_\infty S_D$

F_D Measured drag force, lb

M_∞ Free-stream Mach number

P_r Permeability, the volume of air that will pass through 1 sq ft of material in 1 min at 1/2 in. of water pressure; cu ft/min/sq ft

p_i	Decelerator internal pressure, psfa
p_{t_∞}	Free-stream total pressure, psfa
q_∞	Free-stream dynamic pressure, psf
S_D	Reference area with the AID deployed, 19.63 sq ft
t	Time, sec
α	Model angle of attack, deg

SECTION I
INTRODUCTION

A series of investigations have been conducted in the Propulsion Wind Tunnel (16S) for the National Aeronautics and Space Administration to develop an Attached Inflatable Decelerator System (AIDS). An AID is essentially a low mass, inflatable canopy attached directly to a payload and designed for entry deceleration from supersonic speeds into low density atmospheres such as that of Mars.

The first two tests were conducted in January and August of 1968 and are reported in Refs. 1 and 2. These investigations were made to determine the aerodynamic performance of the AID models and to study the deployment and inflation characteristics using a method of preinflation by evaporation of a liquid solution. The third test, reported in Ref. 3, was conducted in May 1969 to obtain deployment and performance characteristics of an AID system with mechanically deployed inlets used to initiate the inflation sequence.

The two AID models that were tested and reported herein had an inlet capture area that was greatly reduced from the inlet capture area of the previous AID models. The previous models were successfully deployed with inflation times varying from 0.2 to 0.7 sec. This rapid inflation time is desirable to prevent the lightweight fabric from excessive rubbing against itself during the unfolding process. However, to maintain the same inflation time for large-scale AID models would require that the area of the inlets be increased in proportion to the volume of the AID model. Increasing the scale of the models would eventually result in inlets too large to be structurally feasible.

The purpose, therefore, for testing the AID models with smaller inlets was to determine the inflation time and the effect of the smaller inlets on the aerodynamic performance of the AID models.

SECTION II
APPARATUS

2.1 TEST FACILITY

Tunnel 16S is a closed-circuit, continuous flow wind tunnel that presently can be operated at Mach numbers from 1.50 to 4.75. The tunnel can be operated over a stagnation pressure range from 200 to approximately 2300 psfa. The test section stagnation temperature can be controlled through a range from 100 to 620°F. The tunnel specific humidity is controlled by removing tunnel air and supplying conditioned makeup air from an atmospheric dryer.

Details of the test section, showing the model location and sting support arrangement, are presented in Fig. 1 in the Appendix. A more extensive description of the tunnel and its operating characteristics is contained in Ref. 4.

2.2 TEST ARTICLE

The two similar test models consisted of a 120-deg conical aeroshell with a base diameter of 24 in. and an attached inflatable textile canopy that extended to a diameter

of 60 in. including a five-percent burble fence. Each of the models had four mechanically deployed inlets attached to the forward face of the aeroshell at 90-deg intervals as shown in Fig. 2. In addition, the models had four conventional ram-air inlets located just ahead of the burble fence and rotated 45 deg with respect to the forward inlets. Major model details and dimensions are shown in Fig. 3, and wind tunnel installation photographs of the aeroshell model with the decelerator stowed are shown in Fig. 4.

The conical aeroshell was made of aluminum alloy sheet, spun-formed into final shape after an intermediate stabilizing heat treatment. A rigid close-fitting, low-carbon, steel tube served as the transitional support between the sting-mounted internal balance and the aeroshell.

One of the inflatable decelerators (Model 1) was constructed of Nomex® cloth and coated with Viton®, and the other (Model 2) was constructed of Dacron® cloth and coated with Silicon®. The inflatable afterbody was designed for minimum weight by applying the concept of isotensoid design as described in Ref. 5. The decelerator was secured to the forebody by clamping the canopy end bands to the balance housing with steel clamping sections as shown in Fig. 3.

The decelerator was contained in its packaged configuration by a corset-type restraint around the balance housing as shown in Fig. 4a. The loops on the corset were held together by a pull-pin that was attached to a 5-1/2-ft-long bungee cord. The bungee cord was stowed inside an 8-ft-long tube that was attached to the side of the sting support; the forward end of the bungee cord was restrained by a nylon cord that passed through a pyrotechnic cutter. The bungee cord was stretched approximately 2-1/2 ft and the aft end attached to the downstream end of the tube. On a given electrical signal, the pyrotechnic cutter severed the nylon restraining cord, allowing the bungee cord to move the pull-pin rearward, and release the decelerator. Deployment of the decelerator from the base of the aeroshell was then accomplished by releasing the mechanically deployed inlets which were held in the stowed position by a spring-loaded lever attached to another pyrotechnic cutter.

2.3 INSTRUMENTATION

A six-component, strain-gage balance was used to measure model forces to within ±10 lbf for the range of loads measured during these tests. The decelerator internal pressure was measured with a model-mounted, 5-psid transducer. Six motion-picture cameras and a television camera, looking through window ports in the test section walls, were used to document and monitor the test.

Outputs from the balance and pressure transducer were digitized and code punched on paper tape for on-line data reduction. These outputs were also continuously recorded on direct-writing and film pack oscillographs for monitoring model dynamics.

SECTION III
PROCEDURE

The AID unit was carefully packed into the aeroshell storage compartment before wind tunnel test operation was initiated. Once the prescribed test conditions were established, steady-state data were obtained for the undeployed condition. A countdown procedure was used to sequence data acquisition during the AID deployment. The deployment procedure consisted of activating the recording oscillographs and test section cameras, followed by energizing an automatic sequencer system which initiated the signal to the pyrotechnic cutter restraining the bungee cord pull-pin 0.5 sec before initiating the signal to the inlet release mechanism. Upon completion of the AID deployment sequence, steady-state loads were calculated by averaging the analog signals from the balance over a one-second interval.

SECTION IV
RESULTS AND DISCUSSION

Three attempts were made to deploy AID models at free-stream Mach numbers of 3.0 and 4.4 with limited success. The first attempt resulted in a premature, partial inflation because of ram-air leakage around the inlets located in the face of the aeroshell. When the deployment sequence was initiated, the AID failed to deploy because of binding in the inlet deployment mechanism and the bungee pull-pin. No data were obtained, and no further mention is made of this attempt. Before further testing, the clearance around the inlets was sealed with masking tape.

During the second attempt (AID Model 1) a partial failure of the inlet deployment system occurred which resulted in a delayed deployment. Only one of the four inlets opened on command from the firing sequencer, and the decelerator failed to deploy. After approximately 24 sec, the other three inlets opened resulting in a deployment that will be discussed later. Only a limited amount of camera coverage of the deployment was obtained because three of the high-speed cameras ran out of film before the deployment occurred.

The inlet deployment mechanism on the third attempt (AID Model 2) also failed to open the inlets, and no valid deployment data were obtained. The AID model was then deployed, however, by unstarting and then quickly restarting the supersonic flow in the test section. Although the test section flow was unstarted for only 16 sec, and at a very low stagnation pressure (approximately 200 psfa), the permeability of the AID fabric was undoubtedly increased because of the excessive decelerator flagging that occurred during the flow unstart. The forward inlets of Model 2 failed to open even after the model was deployed by the flow unstart; however, inflation of the decelerator was maintained by the aft inlets once they were erected into the airstream.

4.1 DEPLOYMENT CHARACTERISTICS

The deployment time histories of the drag load and internal pressure rise for AID Model 1 are presented in Fig. 5. Time zero represents the time when the mechanically

deployed inlet cutter was activated; however, only one of the four inlets opened at t = 0 sec which was insufficient to initiate deployment of the AID. At t = 24 sec, the remaining three inlets opened and the AID started to unfold and inflate. AID Model 1 required approximately 2.2 sec to reach its peak internal pressure and drag value, compared with 0.7 sec for the similar AID model that was tested and reported in Ref. 3, shown by the dashed line in Fig. 5. This increase in the inflation time was expected because of the reduction in the inlet capture area; however, there was also a decrement in the maximum drag value and internal pressure rise for the AID Model 1. This loss in performance will be discussed further in Section 4.2.

4.2 STEADY-STATE CHARACTERISTICS

The decelerator drag coefficient (C_{D_D}) and corresponding pressure ratio (p_i/p_{t_∞}) are presented in Figs. 6 and 7, respectively, for the two AID models investigated. A comparison of these data was made with the data from similar AID models reported in Refs. 2 and 3. Although all of the AID models discussed were designed to have the same shape when fully inflated, their inlet capture area and fabric permeability varied as shown in the table above Fig. 6.

The internal pressure data for AID Models 1 and 2 indicate that these decelerators were underinflated, resulting in a low drag coefficient compared with data from Ref. 2. The data, in fact, agree more closely with the data from the Ref. 3 AID model that was underinflated because of the high fabric permeability.

As mentioned previously, the permeability of Model 2 was questionable because of the excessive flagging that occurred during test section flow unstart. It should also be pointed out that the aft attachment ring (see Fig. 3) of Model 1 was not sealed between the ring and the balance housing. This connection was a close fit, but some leakage could have occurred to decrease the internal pressure of the AID model. Since the effective permeability of the AID Models 1 and 2 was questionable, it is difficult to conclude whether the poor inflation was the result of the reduced inlet capture area or possibly the increase in the permeability of the models. It has been shown, however, in Ref. 6 that increasing the ratio of decelerator volume to inlet capture area resulted in an increase in the inflation time and a decrease in the afterbody internal pressure. It is believed that the inlet capture area of AID Models 1 and 2 was insufficient to maintain the necessary inflation pressure for good decelerator performance.

Photographs of the AID models at various test conditions are shown in Fig. 8. It can be seen from these pictures that the decelerators were not fully inflated. When these models were inflated statically to the correct pressure ratio for full inflation, the black ring around the decelerator, aft of the aeroshell, coincided with the trailing edge of the aeroshell. With a lower internal pressure than required for full inflation, the AID models became elongated and did not reach their maximum diameter.

SECTION V
CONCLUDING REMARKS

Tests were conducted with two AID models at free-stream Mach numbers from 2.6 to 4.4 to determine the effect of reducing the inlet capture area on decelerator performance.

1. Because of malfunctions of the inlet deployment mechanism, limited deployment data were obtained on only one of the decelerator models.
2. Decreasing the inlet capture area increased the inflation time from less than one second for previous AID models to 2.2 sec for AID Model 1.
3. The AID Models 1 and 2 had poor inflation and a low drag coefficient compared with previously tested low permeability AID models.

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APPENDIX
ILLUSTRATIONS

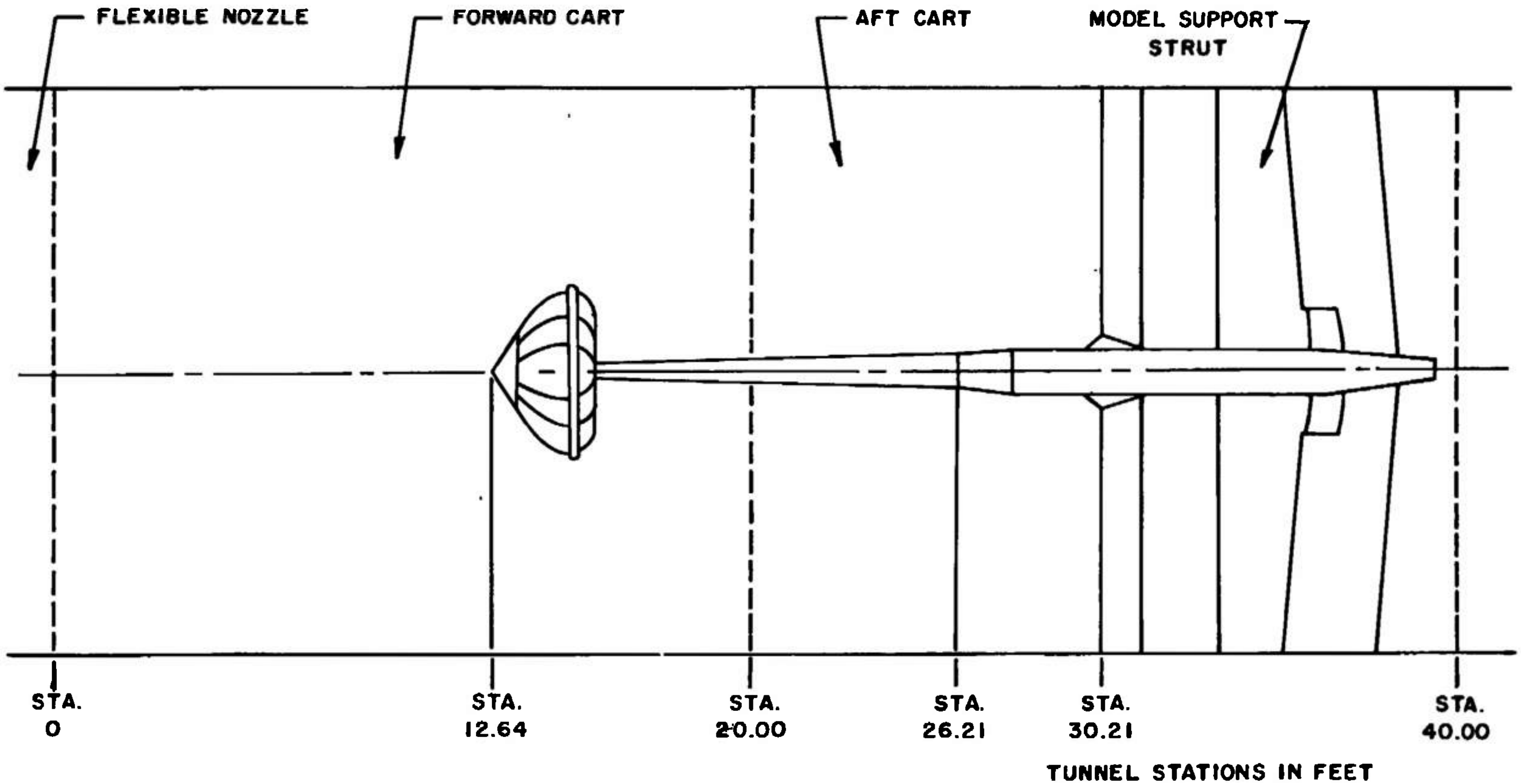


Fig. 1 Location of Model in Test Section

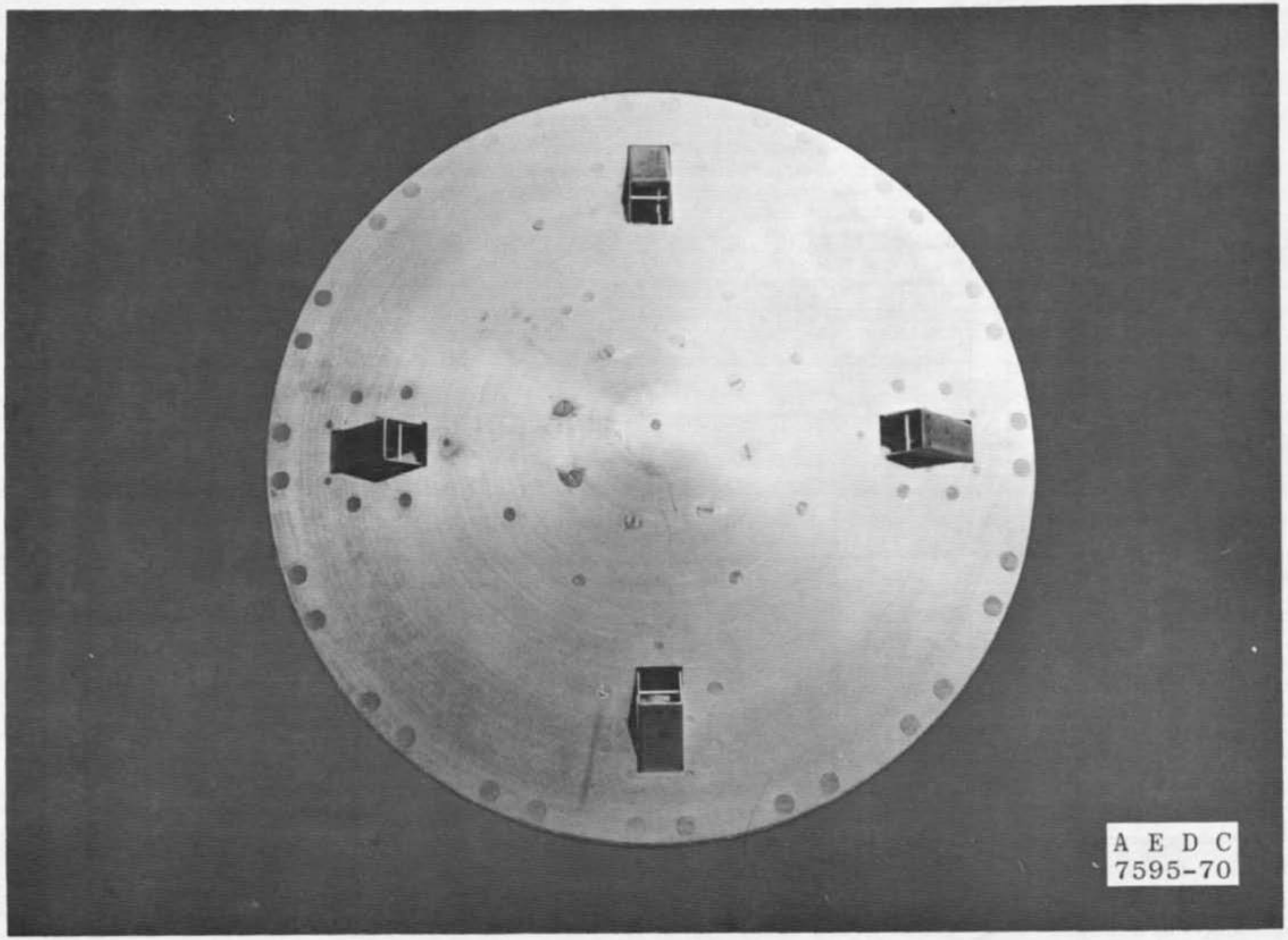
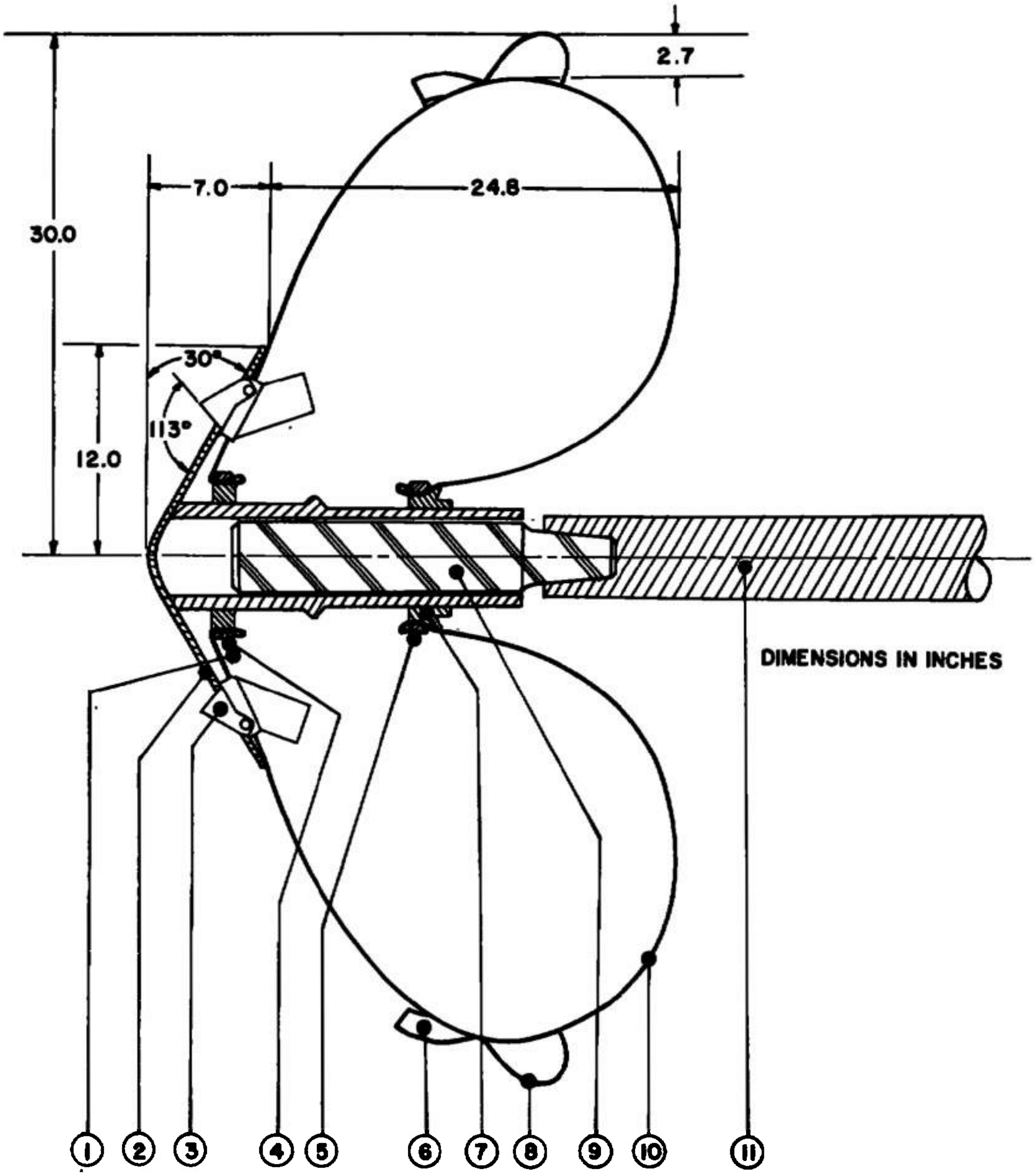
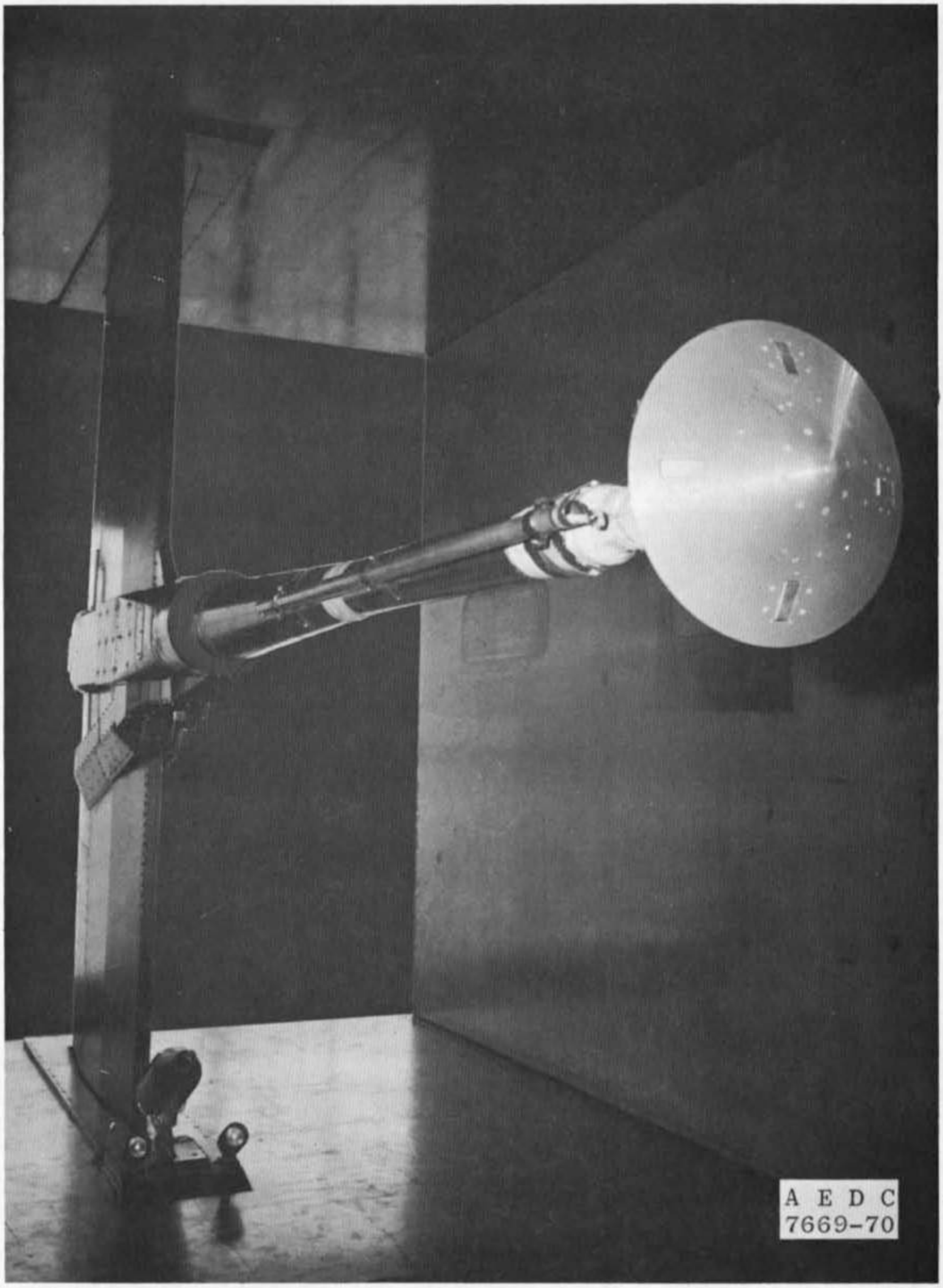


Fig. 2 Photograph of Inlets

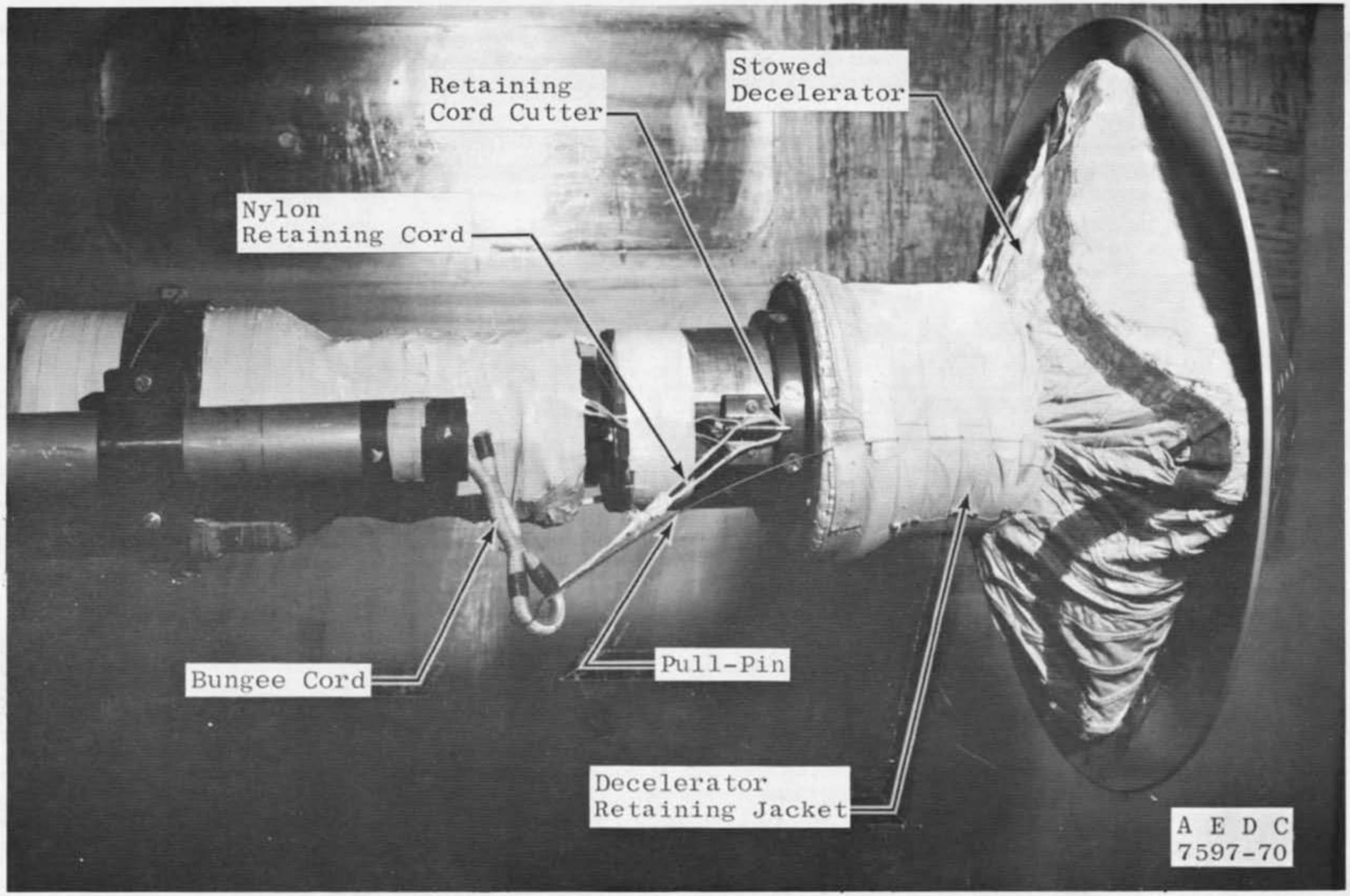


1. DECELERATOR STOWAGE COMPARTMENT
2. AEROSHELL
3. FORWARD RAM-AIR INLETS (TYP 4 PLACES)
4. DECELERATOR CLAMP (FORWARD)
5. DECELERATOR CLAMP (AFT)
6. AFT RAM-AIR INLETS (TYP. 4 PLACES ROTATED 45° WITH RESPECT TO FORWARD INLETS)
7. AFT ATTACHMENT RING
8. BURBLE FENCE
9. SIX-COMPONENT BALANCE
10. INFLATABLE DECELERATOR
11. STING SUPPORT

Fig. 3 Details of AID Models



a. Front Three-Quarter View
Fig. 4 Installation of Undeployed Model in Test Section



b. Side View
Fig. 4 Concluded

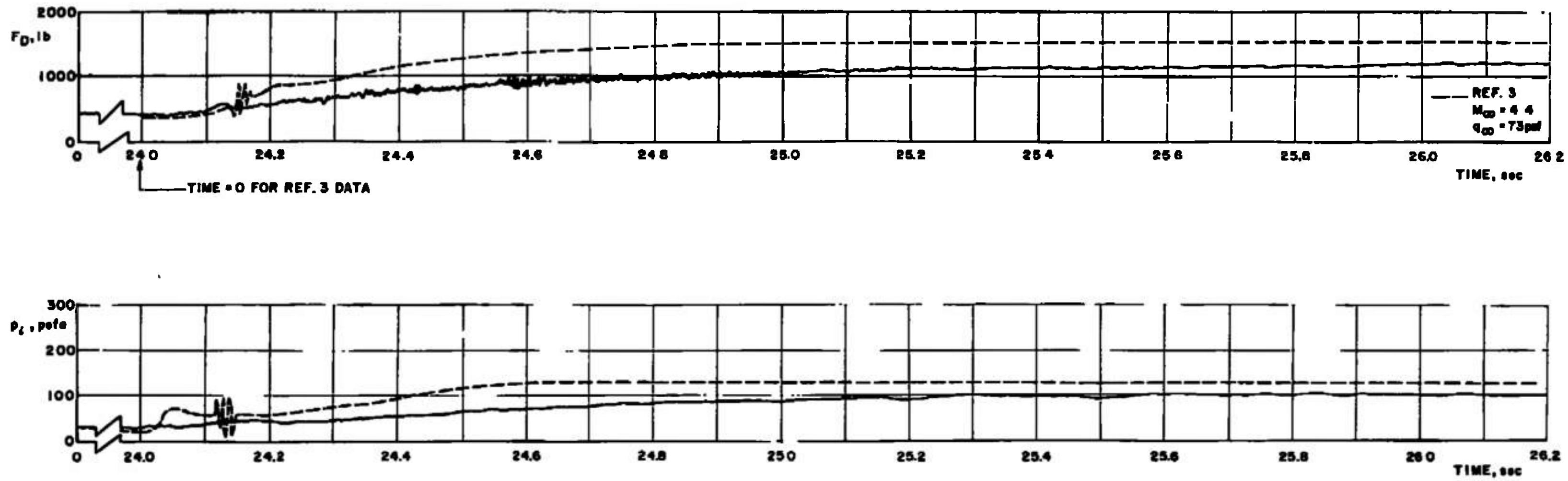


Fig. 5 Decelerator Deployment Characteristics at Mach Number 4.4; Model 1, q_∞ = 76 psf, α = 0

MODEL	SYM	TOTAL FWD INLET CAPTURE AREA, IN^2	TOTAL AFT INLET CAPTURE AREA, IN^2	FABRIC PERMEABILITY, P_r, $ft^3/min/ft^2$
1	○	5.88	10.18	0.002
2	□	NOT OPEN	10.18	0.002
REF. 2	-----	NO INLETS	50.24	0.020
REF. 3	— —	19.64	NO INLETS	10.000

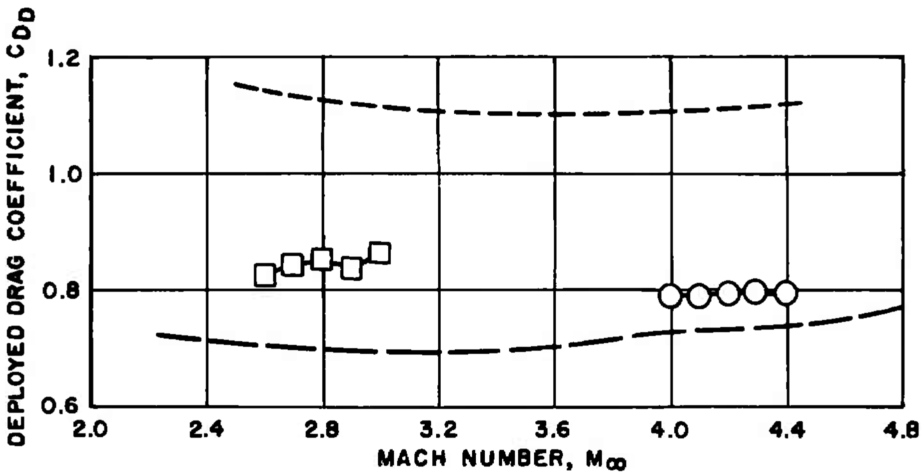


Fig. 6 Effect of Free-Stream Mach Number on the AID Drag Coefficient; $a = 0$

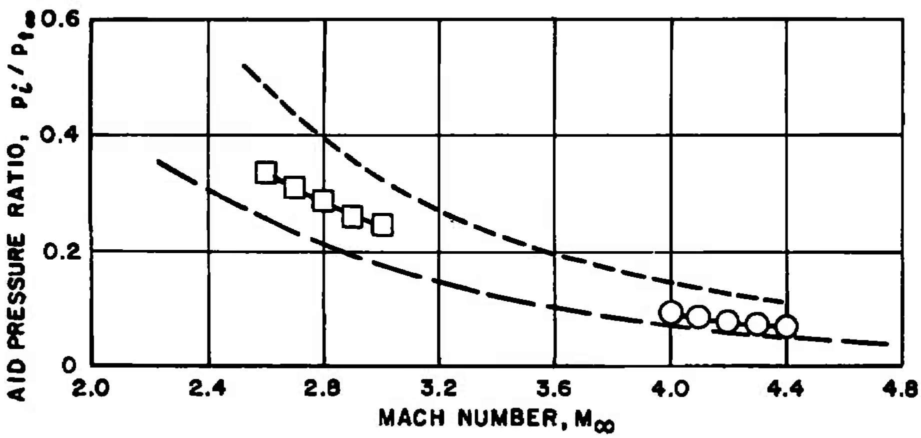


Fig. 7 Effect of Free-Stream Mach Number on the AID Pressure Ratio; $a = 0$

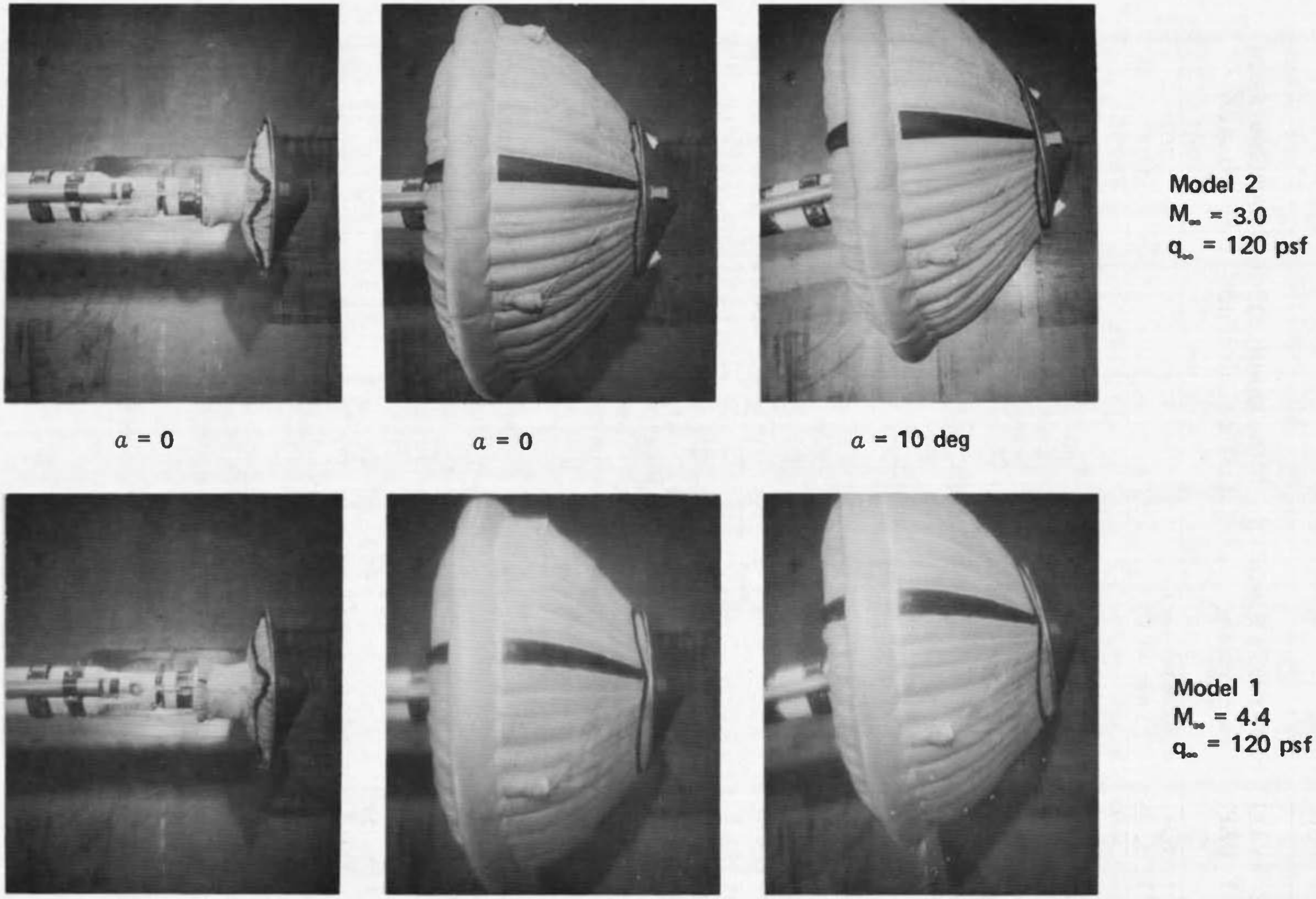


Fig. 8 Photographs of the AID Models at Various Test Conditions

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13. ABSTRACT

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supersonic wind tunnel						
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deceleration						
supersonic flow						

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